PROTECTION OF VEHICLES AGAINST MINES

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Abstract

The paper presents the threats posed by mines and IEDs (improvised explosive devices) to vehicles conducting different combat operations. The typical reaction of a pressure impulse after explosion was presented. The parameters of a pressure impulse having an impact on the hull underside were discussed. The graphic impact of the shape of the hull underside on the propagation of pressure wave resulting from the detonation of the explosive was presented. The structural solutions applied now in the world, able to protect the hull underside against mines, IEDs and RPG-rockets were discussed. The soldier protection means in form of seats with safety belts and protective clothing capable of minimising the impact of an explosion on soldiers in a vehicle were mentioned. A concept of a flexible explosive reactive armour being mounted underneath the hull of an armoured vehicle was presented. The structure of protective armour and its assembly to an armoured vehicle as well as the destructive impact of mines and IEDs containing both blasting charge and shaped charge utilising the principle of either the EFP or a shaped charged jet were discussed. Structural analysis on solutions used world-wide in vehicles resistant to mines was performed and their resistance to mine explosion under the hull and under the wheels was given. The idea of a vehicle with increased resistance to various mines, IEDs and RPG-rockets was presented. The vehicle's hull with suspended flexible explosive reactive armour having the rumple zone in the lower part and the RPG-net on sides, which is mounted to hull's movable arms was proposed. The advantages of proposed above structural solutions were discussed.

Keywords: *armoured vehicle, mines, IEDs (improvised explosive devices), reactive armour*

1. Introduction

Military conflicts and stabilisation missions involve a wide-spread use of different kinds of vehicles, including fighting vehicles, armoured vehicles, personnel carriers, mine-clearing vehicles and the like. They are used to conduct military operations, patrol missions, convoys, mine-clearing-, and routine transport missions.

During these operations, the vehicles are forced to move both on the roads and off-road where they can encounter individual mines (in case of roads) and minefield sectors (off-road) emplaced by the adversary. Considering the above, in order to provide safety to the crew and ergonomic transport conditions, such vehicles should be characterized by high mine- and IED-detonation resistance, as well as resistance to artillery fire and the ability to operate in various terrains and climatic conditions.

All in all, at the vehicle design stage particular attention should be paid to the vehicle hull construction (its shape and armour), its suspension, seat construction and seat fixing method in the crew compartment, as wall as mobility both on- and off-road.

2. Threats posed to the vehicles by IEDs

Currently, various kinds of typical anti-tank (AT) mines, scatterable mines and off-route mines are in the service with armies all around the world. Depending on their construction, typical AT mines can be divided into blast mines and shaped charge (HEAT) mines. They can contain pressure fuses which cause the mine to detonate under the wheel of the vehicle, as well as non-contact fuses (initiated by magnetic influence) which explode underneath the hull of the vehicle. Scatterable mines are most often equipped with non-contact fuses and include a shaped charge. Off-route mines are produced with either the contact- or non-contact fuses but can also be remotely detonated by an operator. They are designed to be effective when detonated next to a side of an armoured vehicle. The threat generated by mines and IEDs is presented in Fig. 1.

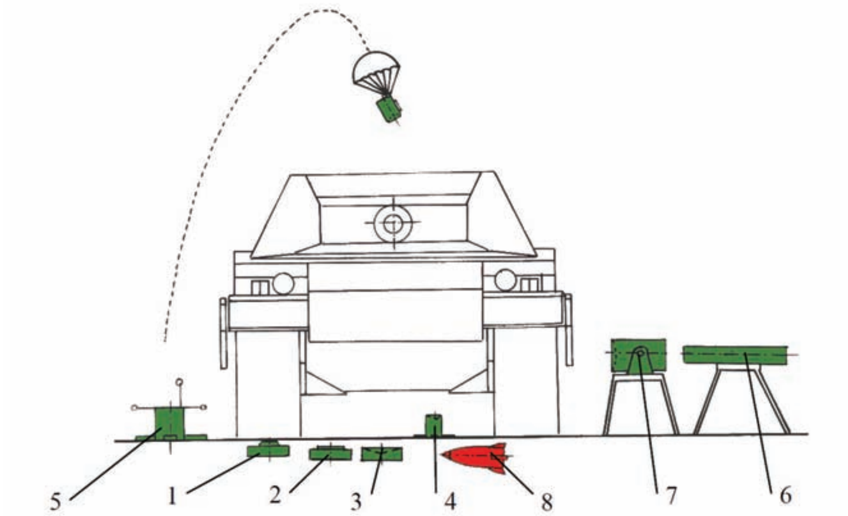

Fig. 1. Threat caused by typical AT mines: blast mines, scatterable mines, off route-mines and IEDs: 1 – typical pressure-activated AT blast mine, 2 - typical non-contact fuse AT blast mine, 3 - typical non-contact fuse AT shaped charge mine, 4 – scatterable AT shaped charge mine whose impact is exerted underneath the hull of the vehicle, 5 – scatterable AT shaped charge mine whose impact is exerted on the upper hemisphere of the hull of the vehicle, 6 – rocket-propelled off-route shaped charge mine, 7 – off-route EFP (explosively formed penetrator) mine, 8 – IED

Depending on its construction, typical AT blast mines contain ca. 9.0 kg explosive. Detonation of such a mine generates a pressure impulse which exerts impact on the wheels and suspension or the hull underside thus eliminating the commonly used tanks and armoured personnel carriers (APCs) from the battle field. Further, depending on their construction scatterable AT shaped charge mines inflict damage either to the hull underside (high-velocity partial stream of metal, EFP) or to the hull top (EFP). Modern shaped charged mines (both the conventional ones and scatterable ones) which impact the lower parts of hull can pierce even a 150 mm armoured plate.

The fighting vehicles and carriers in service with the armies world-wide are not resistant to the impact of such mines.

3. Impact of explosion on the vehicle hull underside

The efficiency (effectiveness) of the impact of explosion on hull underside depends on the magnitude of shockwave resulting from the detonation of the mine explosive. Fig. 2 presents typical reaction of a pressure impulse as dependent on the stand-off distance (distance from the centre of the explosion, for example from the mine, to the vehicle hull underside). The energy of shock-wave pressure impulse is outlined as area marked in the Figure below.

A vital parameter to be considered when analysing the impact of pressure impulse of the hull underside is the maximal pressure value at the wavefront [1].

$$\Delta P_2 = \frac{\varphi(k) \cdot E}{R^3}, \tag{1}$$

where:

ΔP_2 – maximal pressure value at the wavefront,

φ(k) = 0,1038 – for strong explosion in the air,
k – vapour/gas isentropic exponent in the area affected by the shockwave,
E – tensile (Young's) modulus of hull underside,
R – stand-off distance (distance between the mine and the hull underside).

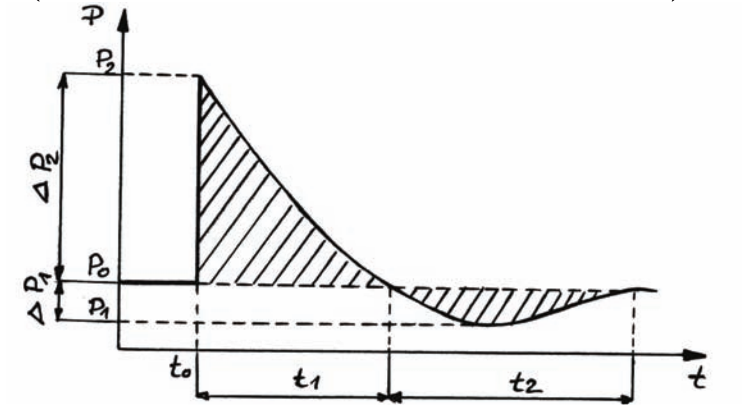

Fig. 2. Shock-wave pressure impulse:
P_2 – maximal pressure value at the wavefront, P_1 – minimal pressure value at the wavefront, P_0 –atmospheric pressure (undisturbed medium), t_1 – duration of shock-wave positive pressure, t_2 – duration of shockwave negative pressure, ΔP_2 – maximal positive pressure at the wavefront, ΔP1 – maximal negative pressure at the wavefront

What results from the above formula is that maximal pressure value at the wavefront ΔP_2 which affects the hull underside decreases with increasing stand-off distance proportionally to its third power. In reality, however, shockwave pressure impulse effecting the vehicle underside, particularly under a flat-bottomed platform is much higher than what can be seen in Figure 2. Numerical analysis of explosion’s impact on flat-bottomed vehicle conducted at Military University of Technology’s Department of Mechanics and Applied Computing Science revealed that the pressure impulse has been magnified as the result of pressure wave reflecting from the flat bottom [2].

Figure 3 illustrates the impact of the shape of the hull underside on the propagation of pressure wave resulting from the detonation of the mine or IED explosive. If pressure value at the wavefront P_0 is resolved into two components: one normal to the hull underside plane P_N and one tangent to the hull underside plane P_T, one can see that normal component (perpendicular to the hull surface), which effectively impacts the hull and causes its damage, is much greater in case of a flat-bottomed platform than in case of a V-shaped platform (hull).

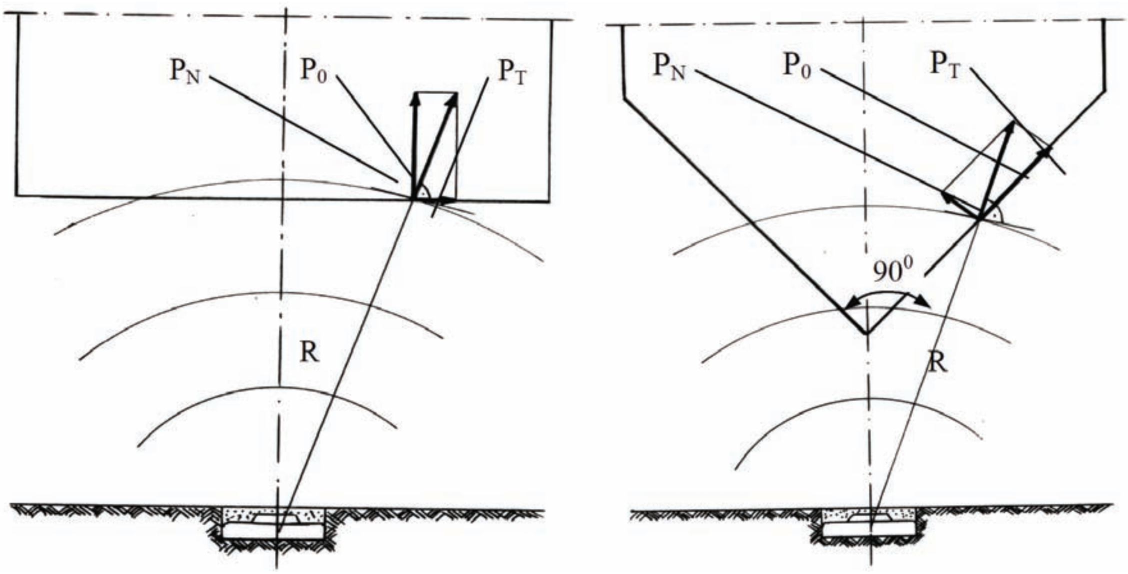

Fig. 3. Graphic representation of the impact of pressure wave on flat-bottomed hull and V-shaped hull

For a specific stand-off “R” (Fig. 3), the pressure P_N effecting the V-shaped hull ($\alpha = 90^0$), is 2,23 times lower than the pressure effecting the flat-bottomed hull.

Having in mind the above, one can observe the growing tendency towards designing a more streamlined hull underside and as high ground clearance as possible in case of vehicles exposed to threat posed by mines and IEDs.

4. Means of improving the vehicle’s resistance to mine and IED explosion

4.1. Vehicle subassemblies and armour (shield)

Armoured vehicles are characterized by integral bodies with suspension and drive train being either mounted directly to the vehicle hull, or to the hull via a special frame. One of the means of increasing the resistance to mine and IED explosion is using a V-shaped hull (Fig. 4) or mounting a V-shaped armour mounted above the frame. These technical solutions allow for the explosion energy to be dissipated therefore mitigating and minimising its impact on the hull underside.

Fig. 4. Hull underside (on the left)and a V-shaped armour:
1 – hull; 2 – frame; 3 – armour (shield)

In turn, RPG-nets (screens) are mounted in order to protect the sides of the hull against the impact of off-route mines which utilise the principle of a HEAT (High Explosive Anti-tank Warhead) missile, as well as against RPG-7 rockets (Fig. 5) used by soldiers.

Fig. 5. APC with addend RPG-net

There exists a number of different anti-rocket-propelled-grenade RPG-7 nets or bar armour systems [3] - BAE Systems’ L-ROD, RUAG’s LASSO, Qinetiq North America’s LAST Amor

(Qinetiq RPGNet) and the like. They are made either of steel bars, composite slats or in the form of a mesh/net. These shields are to mitigate/distort the impact of the shaped jet (as much as it is possible) through deformation (or destruction) of the liner and increase the stand-off the distance, that is moving the detonation of a shaped charge away from the hull armour.

In some armoured vehicles, that is in their drive trains, a specially designed, reinforced wheels (Fig. 6) are used. These also mitigate the impact of IED or mine explosion on the vehicle.

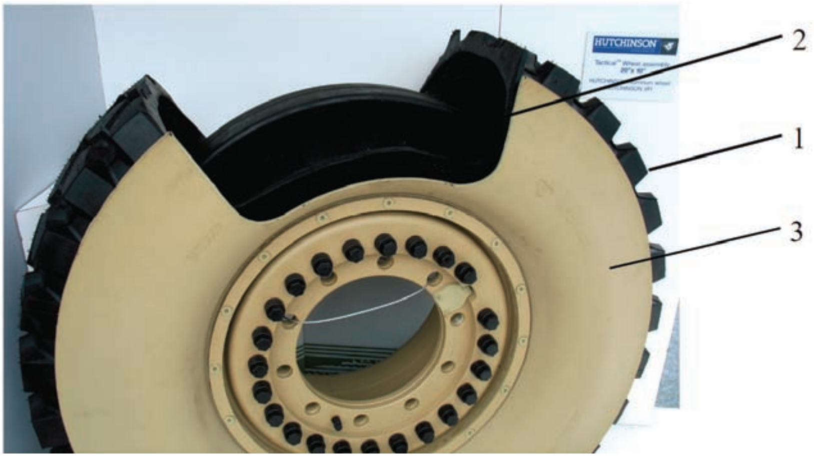

Fig. 6. MRAP (mine resistant ambush protected) reinforced wheel: 1 – tyre, 2 – insert dissipating explosion energy, 3 – tyre shield

4.2 Soldier protection

Special factors minimising the impact of an explosion on soldiers (human occupants) in a vehicle are specially designed seats with safety belts (Fig. 7).

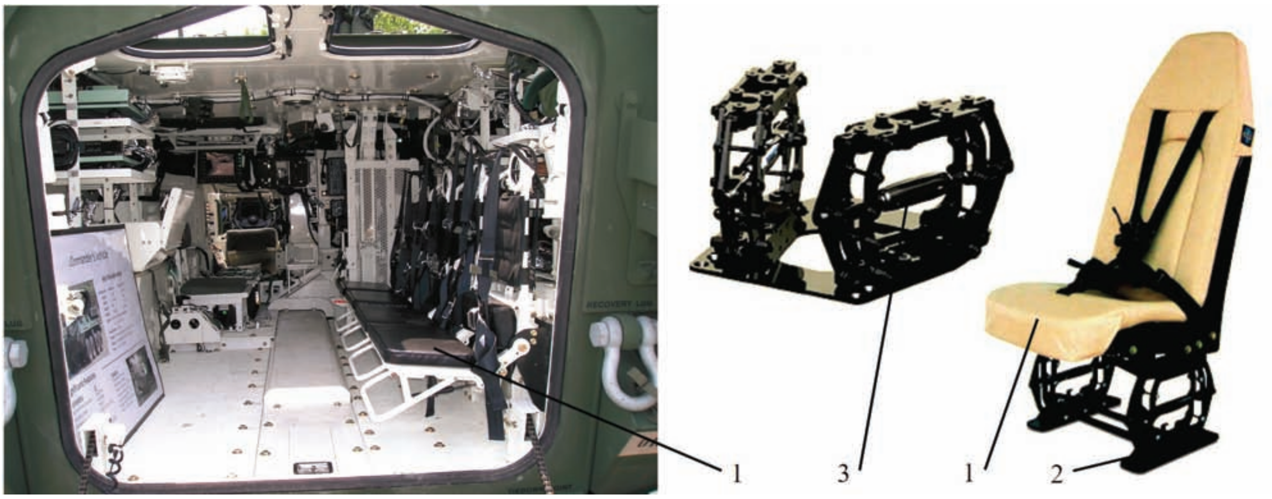

Fig. 7. Crew compartment with seats mounted to the wall of the vehicle (on the left) and individual seat mounted to the floor on the right) [7]: 1 – seat, 2 – seat base, 3 – seat shock absorber

Depending on their construction, the seats are mounted on a bracket either to the floor, to the wall or to the hull ceiling. The seats are to absorb and attenuate muti-directional impacts and hull vibrations as the result of an IED- or a mine blast. One more element mitigating the human effects of a mine or IED blast is the protective clothing [5].

5. A concept of an flexible explosive reactive armour (ERA) for armoured vehicles

The armour increases the protective capability of the hull underside in an armoured vehicle against the destructive impact of various mines and IEDs utilising the principle of either the EFP or a shaped charged jet.

The proposed flexible explosive reactive armour (ERA) consists of a flexible, multi-layered coating with slabs of plastic explosive sandwiched in between. The upper and lower layers are reinforced with steel lines both in perpendicular and longitudinal direction (Fig. 8).

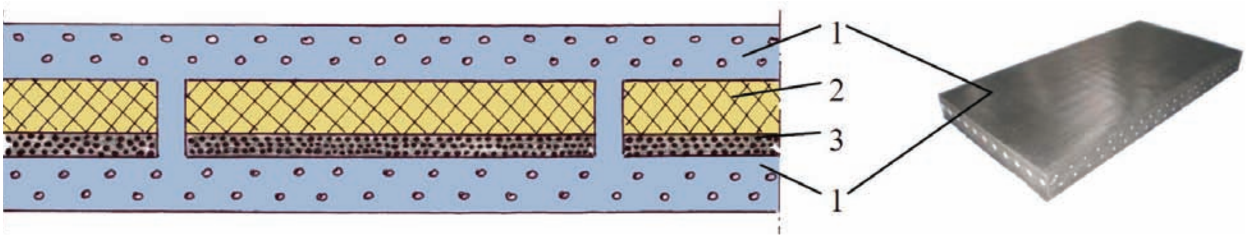

Fig. 8 Structure of the proposed ERA:
1 – flexible coating reinforced with steel lines, 2 – slabs of plastic explosive, 3 – ceramic balls

This frontal part of the armour is mounted to the brackets via a coupling and axis. In turn, the brackets are mounded to the frontal part of a fighting vehicle hull and then directed underneath the hull through cable drum, drive shaft and brackets to the rear of the hull [6].

In travelling order, the flexible ERA occupies position on top where it lies on driving axles of a wheeled carrier or on the bottom of a tank. If the vehicle is to enter the area threatened by mines and IEDs, the flexible, multi-layered ERA is lowered just above the ground surface as the result of lines unreeling from the drum powered from a prime mover (Fig. 9).

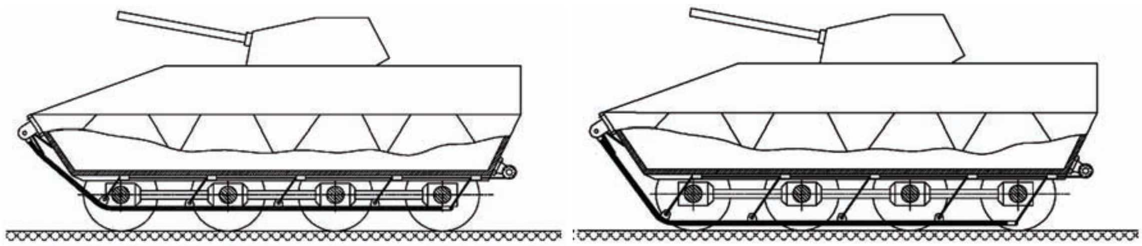

Fig. 9. Armoured carrier with flexible ERA in travelling order (on the left) and threat explosion order (on the right)

What an ERA does in case of mines and shaped charge-based IEDs is either to mechanically disrupt the formation of shaped charge jet or weaken the impact of shaped charge jet as the result of the detonation of the charge inside the ERA (Fig. 10).

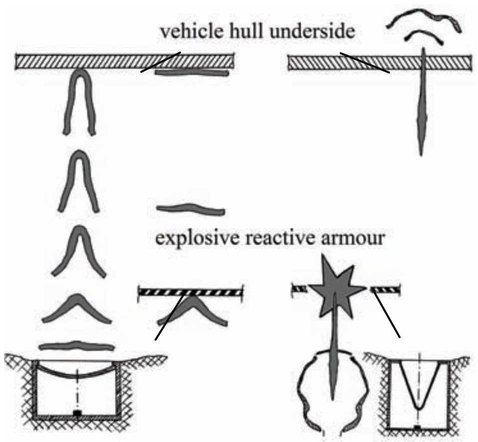

Fig. 10. Explosive reactive armour's reaction to the impact of a shaped charge generating an explosively formed projectile (on the left) and shaped charge jet (on the right)

The obstacle in the form of a flexible ERA which the forming projectile encounters precludes its proper and therefore decreases its effectiveness. In turn, detonation of the explosive within the ERA which ensues following the impact of the mine's shaped charge (plasma) jet limits its penetration ability (similarly as in case of a typical reactive armour) and thus limits the damage done to the hull underside.

In case of a mine- or IED blast, the ERA operating principle consists in weakening the mine/IED detonation products' pressure impulse transferred to the vehicle underside. Some part of this energy is utilized on tossing the flexible ERA whose inertia causes partial dissipation of detonation products along the sides of the vehicle up (Fig. 11).

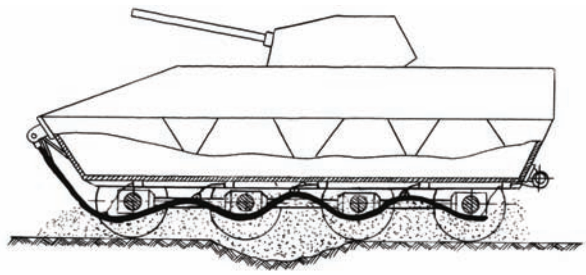

Fig. 11. Weakening of the mine or IED blast on the hull underside as the result of the flexible ERA being tossed up

6. The concept of an armoured vehicle with increased mine resistance

Structural analysis and analysis from the point of view of tactical and technical data on the MRAP solutions used world-wide [4], resulted in a conclusion that they are resistant to a 14 kg (2×TM-57) TNT mine explosion under the hull and a 21 kg TNT (3×TM-57) under the wheels. As was already mentioned, such results have been obtained through application of a proper hull underside geometry and increase of clearance between the hull and the ground to 1,0 m. What is currently known, is that such resistance is insufficient due to increasing application of more and powerful explosives by the adversary.

What results from the operational tactics of insurgent fighters, guerrilla groups and other similar formations is that in particular cases they operate in two-man units. This can be confirmed analyzing the World War II combat operations. During the preliminary phase of the Battle of Kursk, two-man sapper (combat engineer) teams which (as part of cover operations) emplaced mines on sectors of the forefront. These sectors were easily accessible to the enemy tanks but difficult to defend by the Soviets. Thus in modern military conflicts is possible for a two-person team carrying two explosives (4×TM-62 = 30,0 kg TNT) to access the road as part of covert operations, with one person emplacing the mines in the road and camouflaging them, while the other is making the firing circuit at the same time. Therefore new generation of MRAPs should be resistant to detonation of 30 kg TNT both under the wheels and underneath the hull.

A proposal for such a increased resistance vehicle is illustrated in Fig. 12.

The vehicle's hull (1) is V-shaped. Brackets (3) are welded to underside of the hull and the armour (shield) (2) is mounted to the brackets via pins (5). The shape of the shield (2) is similar to the hull's "V" shape. The space between the V-shaped underside and the shield is the rumple zone (4). This is where either the "sandwich", a "honeycomb" or foamed flexible filling is inserted. The vehicle is also mounted with the above-mentioned flexible ERA (6) attached in such a way that it is lead over the better part of the drive axles and is hanging in place via a rope system under the vehicle's hull. Further, on the lower and upper part of the sides of the vehicle cantilever jibs are mounted. The RPG-nets (7) rest and are mounted on these jibs. This structure operates within a straight line mechanism. In travelling order the RPG-net is located by the sides of the vehicle and if there is a need of going through terrain where RPG threat is high or where HEAT missiles may be used, the net is moved away from the sides of the vehicle. It is easier to operate the vehicle in urban area, in a forest or where vegetation is otherwise high and dense, if this net is near the sides of the vehicle. If a buried mine, an AT blast mine or an IED is detonated, the detonation energy is directed towards tossing the flexible ERA (6) up, tearing it, shearing the pins (5) which hold the shield (2) to the brackets (3), folding/denting the shield (2) and the rumple zone (4). One can see that before the buried mine- or IED detonation energy impacts the hull underside, it will be reduced significantly.

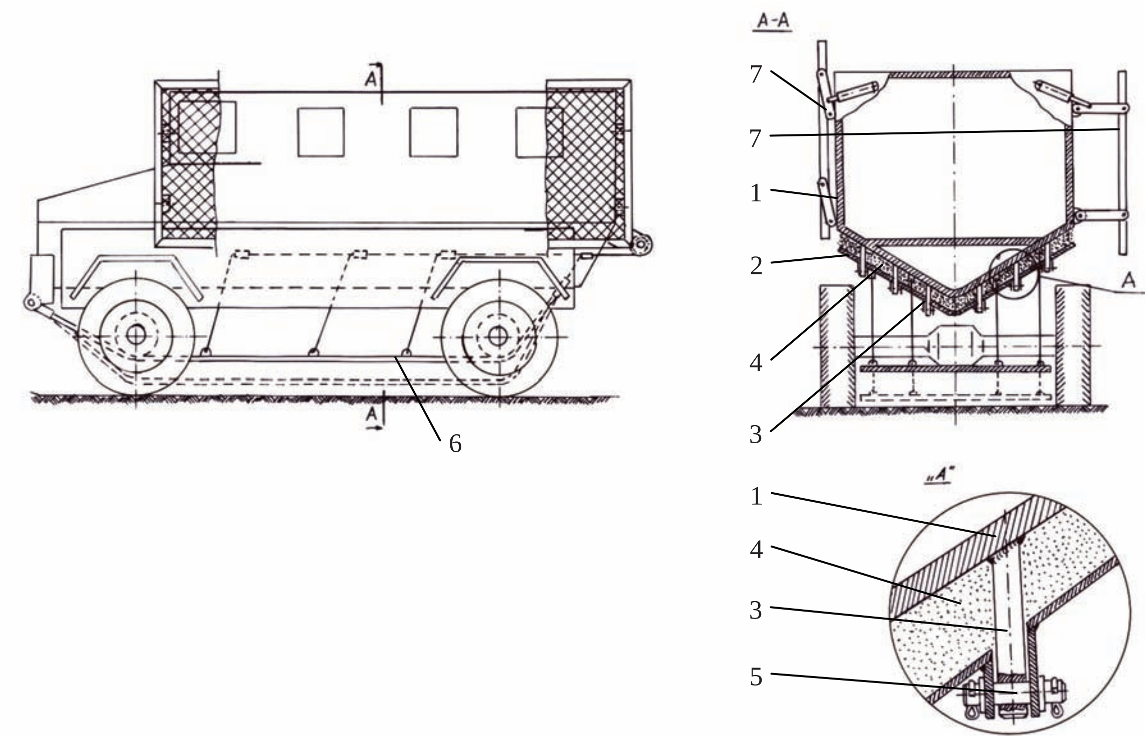

Fig. 12. Increased mine- resistance vehicle – idea:
1 – hull, 2 – hull armour (shield), 3 – armour bracket, 4 –rumple zone, 5 – pin, 6 – flexible ERA, 7 – RPG-net

7. Conclusions

1. The conflicting sides of the contemporary military conflicts widely employ mine warfare, that is the use of various AT mines, IEDs and RPG-7 rocket-propelled grenade launchers.
2. There is a need of increasing the vehicle occupants' survivability and safety in the face of mine/IED/RPG threat.
3. Optimal (streamlined) vehicle hull underside design, its reinforcement and increased ground clearance decreases the efficiency of the mine and IED detonation pressure.
4. The idea of employing a flexible ERA is one of the possible means of increasing the protection level of the hull underside's resistance to the above-mentioned range of threats.
5. There is a demand to develop an armoured vehicle which could withstand the detonation of a mine or IED containing 30 kg TNT.

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